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Original Research

Potential effects of climate change on the risk of accidents with poisonous species of the genus *Tityus* (Scorpiones, Buthidae) in Argentina

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ABSTRACT

The temporal pattern of co-occurrence of human beings and venomous species (scorpions, spiders, snakes) is changing. Thus, the temporal pattern of areas with risk of accidents with such species tends to become dynamic in time. We analyze the areas of occurrence of species of Tityus in Argentina and assess the impact of global climate change on their area of distribution by the construction of risk maps. Using data of occurrence of the species and climatic variables, we constructed models of species distribution (SMDs) under current and future climatic conditions. We also created maps that allow the detection of temporal shifts in the distribution patterns of each Tityus species. Finally, we developed risk maps for the analyzed species. Our results predict that climate change will have an impact on the distribution of Tityus species which will clearly expand to more southern latitudes, with the exception of T. *argentinus*. T. *bahiensis*, widely distributed in Brazil, showed a considerable increase of its potential area (ca. 37%) with future climate change. The species T. *confluens* and T. *trivittatus* that cause the highest number of accidents in Argentina are expected to show significant changes of their distributions in future scenarios. The former fact is worrying because Buenos Aires province is the more densely populated district in Argentina thus iable to become the most affected by T. *trivittatus*. These alterations of distributional patterns can lead to amplify the accident risk zones of venomous species, becoming an important subject of concern for public health policies.

1. Introduction

Understanding the factors that shape the distribution of species is a central objective of ecological and biogeographic. studies (Brown et al., 1996). The Grinnellian niche – the climatic conditions where a given organism can persist – is the principal determinant of the distribution of species (Higgins et al., 2012; Soberón, 2007). Thus, knowledge about the factors that determine the geographic distribution of a given species provides information not only about where to find it but also where and how it can interact with the rest of the species (Ehrlén and Morris, 2015).

The *Spatial Distribution Models* (SDM) are strong tools to infer from present-day climate, the occurrence of a given species within the geographic space (Elith and Leathwick, 2009; Peterson, 2011). However, man is currently altering the planet's climatic conditions in unprecedented ways (IPCC 2013). In this scenario, SDMs allow to project the patterns of distribution into hypothetical future climatic conditions thus helping to understand how species will respond to eventual climate change (e.g. Wiens et al. 2009, Loyola et al. 2012, Porfirio et al. 2014).

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In the last decades, humans have exerted enormous pressure on natural systems through the expansion of its own distribution because of urban growth, increasing exploitation of natural resources, and conversion of natural habitats into agroecosystems (Lawler et al., 2013; Venter et al., 2016). This strong impact on biodiversity not only leads to the loss of species of medicinal, commercial and evolutionary value, but to an increasing contact between man and wild species (Conover, 2002). One of the central concerns is the interaction between humans and poisonous species such as snakes, spiders and scorpions, progressively becoming a relevant area of the public health administration of many countries (Kasturiratne et al. 2008; Ediriweera et al. 2016). Furthermore, the geographic distributions of poisonous species are being modified as a consequence of global climate change (e.g. spiders: Saupe et al. 2011; snakes: Nori et al. 2013; Yañes-Arenas et al. 2016). As a consequence, alterations of the temporal patterns of co-occurrence of venomous species and human beings do occur and accident risk areas will present special spatial dynamics as time passes. In this sense, it is essential that public health decision-making takes into consideration this worldwide phenomenon. Considering poisonous animals, accidents with scorpions are among the most alarming from an epidemiological point of view (Day et al., 2004; Chippaux and Goyffon, 2008). About 1.5 million cases of envenomation by scorpion stings occur annually worldwide with a ~0.2% risk of a fatal outcome (Chippaux and Goyffon, 2008). Accidents tend to be more frequent in adults (however, see de Roodt et al. 2003) but in children the rate of lethality can be up to ten times higher (Chippaux and Goyffon, 2008). There are approximately 2300 scorpion species worlwide, distributed in 208 genera of 20 families (Santibáñez-López et al. 2016). However, only 30 are considered potentially dangerous to humans (Chippaux and Goyffon, 2008). Of the 50 species known in Argentina, *Tityus* C.L. Koch is the only genus of medical relevance (De Roodt et al. 2003; de Roodt 2014, de Roodt et al. 2014). *Tityus* comprises more than 140 Neotropical species (Fet et al., 2000) of which only six inhabit Argentina: *T. argentinus* Borelli, *T. bahiensis* (Perty), *T. confluens* Borelli, *T. paraguayensis* Kraepelin, *T. trivittatus* Kraepelin and *T. uruguayensis* Borelli. Of these, only *T. confluens*, *T. trivittatus* and *T. bahiensis* can produce fatal accidents (Ojanguren-Affilastro, 2005).

The aim of this study was to analyze using SDMs the potential areas of occurrence of *Tityus* species in Argentina, and to estimate the potential impact of future climate change on their distributional patterns. Finally, we established risk maps for all affected Argentine provinces for present-day and future climatic conditions.

2. Materials and methods

2.1. Obtention of data: occurrence and climatic variables

Six *Tityus* species are recognized for Argentina (see Introduction). Recently however, the presence of a seventh species (*T. serrulatus* Lutz and Mello) was recorded in Corrientes province (Camargo and Richiardi, 2000). This species is widely distributed in Brazil and is considered one of the most dangerous in the world (Pucca et al., 2015). Thus, we obtained data of occurrence of all seven species with proven or putative existence in Argentina. Occurrence data were obtained from the Global Biodiversity Information Facility (GBIF, www.gbif.org) databases and from the excellent monograph by Ojanguren-Affilastro (2005). All data were carefully examined to eliminate doubtful or duplicated occurrence records. For *T. uruguayensis* and *T. paraguayensis* the number of records (<10) was insufficient for performing SDM. Such a low number of occurrences affects the reliability of the SDM (Stockwell & Peterson, 2002). Thus, the latter two species were not included in our analyses. Robust data were effectively obtained for *T. argentinus* ($n = 43$), *T. bahiensis* ($n = 25$), *T. confluens* ($n = 55$), *T. trivittatus* ($n = 60$), and *T. serrulatus* ($n = 73$).

We obtained data of 19 climatic variables for the present (1950–2000) from the WorldClim database (Hijmans et al., 2005). These variables are derived from temperature and rainfall information. All climatic variables were used at a resolution of 2.5 min (~5 km). Because the variables to be input in the model must be independent we analyzed their colinearity using Pearson's correlation analysis. Of the original 19 variables we selected those six with the highest biological relevance that showed a low correlation ($r < 0.75$) in the study area (South America): Bio7 – annual thermal amplitude; Bio11 – mean temperature of the coldest season; Bio15 – precipitation seasonality; Bio16 – precipitation of the rainiest season; Bio17 – precipitation of the driest season; and Bio18 – precipitation of the warmest season.

For the projection of our models into the future, we used analog climate layers from general circulation models (GCM). For projections into 2070, we used the CCSM4, GISSE2-R and MIROC5. We also made projections into an intermediate scenario, RCP6.0, that establishes that carbon emissions will cause a mean temperature rise of 2.2 °C (1.4–3.3) by 2080–2100 (IPCC, 2013).

2.2. Models of species distribution and risk maps

The SDMs of *Tityus* species were performed with maximum entropy algorithm in Maxent software (Phillips et al., 2006). We chose this algorithm because it only uses presence points and shows a higher performance than others (Elith et al., 2011). The performance of the model was assessed by the Area Under Curve method (AUC) (Peterson et al., 2008). AUC evaluates the model through the relationship between the correctly predicted presences (sensibility) and the erroneously predicted absences (1 minus specificity). The group of data was also divided using 75% as training data and 25% to evaluate the model's robustness. Then the whole dataset was used to develop the model.

We first constructed the models under the current climatic conditions, and then we projected them for the future climate GCM, GISSE2-R, and MIROC5 (year 2070) in the RCP6.0 scenario. The continuous probability maps of occurrences generated by Maxent were transformed into binary maps, where absence (0) is established below a

certain threshold, and above the threshold, presence (1). To define the threshold we used the minimum 10% to establish the lowest probability of the adequate climate (Escalante et al. 2013). The binary maps of present and future were combined in the DIVA-GIS software (http://www.diva-gis.org/). We finally generated a map where changes in the temporal patterns of distribution of each scorpion species can be detected (Stability, Expansion, and Retraction).

Finally, we created an accident risk map for *Tityus* species. To do this, each species was weighted on the basis of its biological risk of accidents in Argentina and the dangerousness of its venom assigning values of 0.5 to *T. argentinus*, 1.0 to *T. bahiensis*, 1.5 to *T. confluens* and 2 to *T. trivittatus* (*T. serrulatus* was not included in the risk map because it has a low probability of becoming established in Argentina; see Results). The risk maps of all species were multiplied by their respective risk values, stacked and added up.

3. Results

The models for all five species showed an optimal performance with values of AUC exceeding 0.95: *T. argentinus*: 0.99; *T. bahiensis*: 0.98; *T. confluens*: 0.96; *T. serrulatus*: 0.96 y *T. trivittatus*: 0.97). The suitability maps of all species were concordant with the distribution patterns proposed in the literature (Appendix A, Fig. S1). In Argentina, *T. argentinus*, showed that the best climatic conditions for its occurrence correspond to Tucumán province, western Santiago del Estero, central Salta, and eastern Jujuy (Fig. 1(a)). *T. bahiensis* showed predominance in northeastern Argentina including the provinces of Misiones, Corrientes, northern Santa Fe, and eastern Chaco and Formosa (Fig. 1(b)). The highest suitability values for *T. confluens* corresponded to north-central Argentina (Fig. 1(c)). The best climatic conditions for *T. trivittatus* were observed in northeastern Argentina with the exception of Misiones province (Fig. 1(d)). Finally, *T. serrulatus* did not show favorable climatic conditions within the Argentine territory with the exception of a small region in central Tucumán province (Fig. 1(e)).

From the future projections (RCP6.0-2070 scenario) we were able to show that models CCSM4, GISSE2-R, and MIROC5 were concordant and highly correlated between them ($r > 0.85$) (Appendix A, Table S1). Thus, only the CCSM4 model is presented. The future projections show a clear trend of all species except *T. argentinus* to expand their distributions towards south (Fig. 1(a)–(d)). In the case of *T. argentinus*, its area of occupancy is expected to decrease with the largest area losses towards the eastern part of its original distribution (Table 1, Fig. 1(a)). In contrast, *T. bahiensis, T. confluens* and *T. trivittatus* show a clear future increase of their original distributions (Table 1, Fig. 1(b)–(d)).

The risk map for the present shows that the areas with a higher probability of serious accidents with scorpions correspond to central and northern Santa Fe province, eastern Chaco province, and northern Córdoba and Tucumán (Fig. 2(a)). Future projections predict intense changes in the zones at risk. The most alarming zones are central-southern Santa Fe, the whole Córdoba province, southern Corrientes, eastern Entre Ríos, southwestern Tucumán, and eastern San Luis (Fig. 2(b)).

Table 1
Climatically suitable areas (km^2) in the present and future (2070: RCP 6.0 scenario) for *Tityus* species in Argentina.

Species	Current area	Future area	Gain or loss
T. argentinus	190,350	179,050	−11,300
T. bahiensis	462,575	635,475	172,900
T. conflens	1,072,675	1,210,700	138,025
T. trivittatus	934,675	1,024,750	90,075

4. Discussion

Scorpions are a fascinating group of arthropods of great antiquity (ca. 450my, and although only about 30 species worldwide are really dangerous for humans due their highly toxic venoms, they tend to be considered agents of evil since antiquity (Polis, 1990). Nevertheless, those species that can put in risk human health and life are worthy of consideration from the medical point of view. Our study using SDMs revealed for the first time the potential geographic distributions of scorpions of the genus *Tityus* in Argentina. Envenomation accidents by scorpions stings are generally restricted to tropical and subtropical regions (Borges et al., 2012). However, our results predict that climate change with its steady increase in global warming, will have a notorious impact in the patterns of distribution of *Tityus* species that will clearly extend to more southern latitudes. A comparable situation has been observed in Argentine poisonous snakes where species of the genera *Crotalus* (rattlesnakes, *serpientes de cascabel*), *Bothrops* (*yararás*), and *Micrurus* (coral snakes, *coralillos*) accompanied climate change with a clear shift of their distributions towards south (Nori et al., 2013). This trend is expected for many tropical and subtropical species of vertebrates and invertebrates when a sustained increase in temperature allows the colonization of new previously limiting habitats leading to an expansion to higher latitudes (Parmesan et al., 1999; Vanderwal et al., 2013). These potential distributional changes may lead to an amplification of the accident risk zones of poisonous species. Then, the relationships of co-occurrence of human beings and venomous species in Argentina are expected to vary spatially and temporally.

Tityus argentinus was the scorpion species for which less changes are predicted: new favorable climatic conditions are only expected in Catamarca province (Fig. 1(a)). Also, this species was the only one to show a potential reduction of its geographic distribution (Table 1, Fig. 1(a)). Furthermore, *T. argentinus* is considered the less dangerous of the Argentine *Tityus* species with no records of fatal accidents attributable to it (Salomón 2005; de Roodt et al. 2014).

On the other hand, our study highlights that climate change may have a significant effect on the distributional patterns of the other examined species (*T. bahiensis, T. confluens* and *T. trivittatus*) where a clear southward shift of their distributions is predicted (Fig. 1). Currently, *T. bahiensis* is frequently found in Misiones province (de Roodt

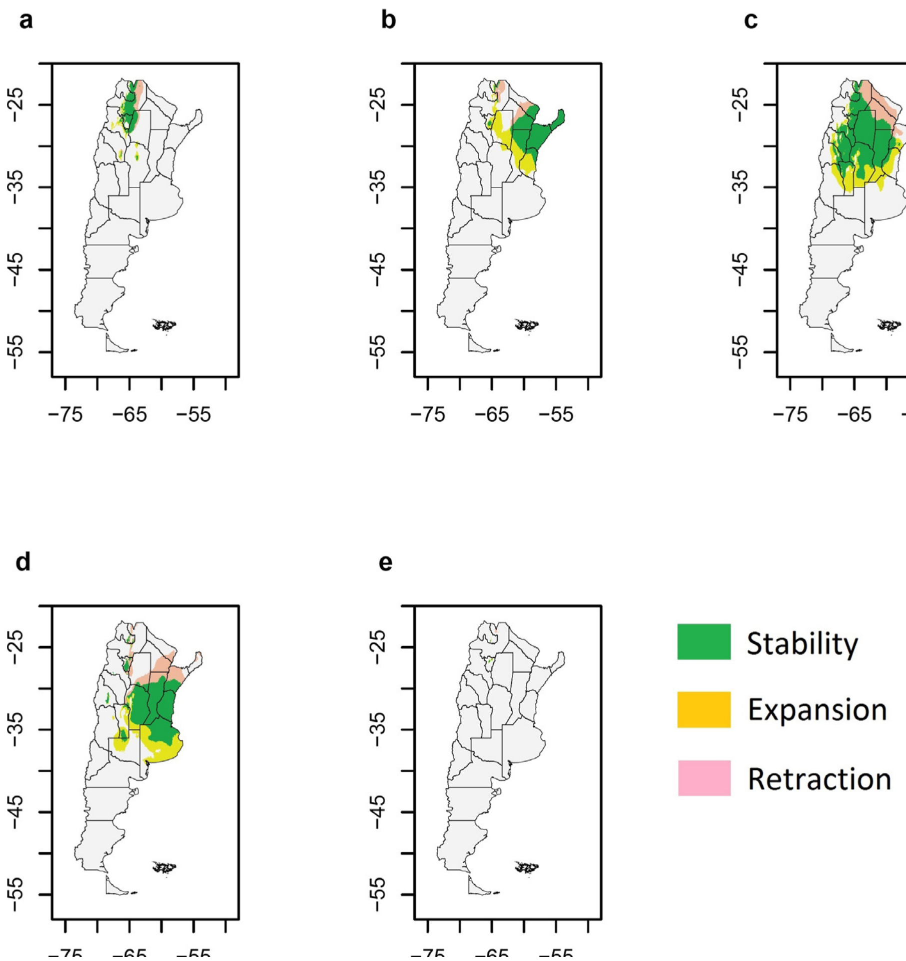

Fig. 1. Changes in suitable climatic areas between present and future condition (2070: RCP 6.0 scenario) for five species of genus *Tityus* of Argentina: (a) *T. argentinus*; (b) *T. bahiensis*; (c) *T. confluens*; (d) *T. trivittatus* and (e) *T. serrulatus.* The green color corresponds to stable areas in present and future, yellow areas are those that will be favorable in future and pink areas those that will be unfavorable in the future (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 2014). To this day, no serious cases of envenomation with this species have been reported in Argentina (de Roodt et al., 2014). However in Brazil, where this species is widely distributed many severe cases of envenomation are continuously reported (Bucaretchi et al., 2014). A worrisome situation is that this species is frequently found in urban settings causing the highest number of accidents in big metropolises such as São Paulo city (von Eickstedt et al. 1996). The analysis of the possible effects of climate change on the distribution of *T. bahiensis* shows a clear significant southward shift of the area of occupancy in Argentina involving a ca. 37% increase of the potentially favorable area (Table 1). An alarming point is that the future climatically favorable regions for the species overlap large urban centers such as Santa Fe, Resistencia, Santiago del Estero and Tucumán cities (Fig. 1(b)). This predictions turn *T. bahiensis* into a foreseeable problem for the Argentine public health system.

The two species that are currently of most public health concern in Argentina, namely *T. confluens* and *T. trivittatus* (Álvarez Parma and Palladino, 2010; de Roodt et al., 2009) also showed significant shifts of their geographic distribution in the future scenarios (Fig. 1(c) and (d)). There is ample evidence that venom of these two species is highly toxic and dangerous for human beings (Álvarez Parma and Palladino, 2010; de Roodt et al., 2009; De Roodt et al., 2003; Saracco et al., 2006). *T. confluens* is involved in death reports of people in many provinces of northwestern Argentina such as Jujuy, Catamarca and Tucumán (de Roodt et al., 2014). On the other hand, SDM projections for *T. trivittatus* show that the main increase in geographic distribution is predicted for the potentially favorable areas of Buenos Aires province, the more densely populated district in Argentina (Fig. 1(d)). Contrary *to T. confluens, T. trivittatus* easily adapts to urban environments and is the main cause of deaths by scorpion stings in Argentina (de Roodt et al., 2014). This behavior of *T. trivittatus* highlights a limitation of our study using SDMs because only the external climatic characteristics were considered but *T. trivittatus* adapts easily to urban settings using subterranean galleries, drainpipes, and cavities and crevices of buildings (Ministerio de Salud, 2011, de Roodt et al., 2014). These

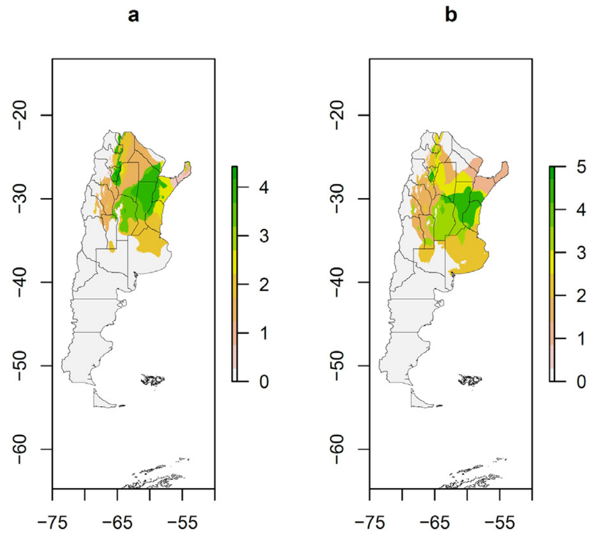

Fig. 2. Accident risk map for present and future (2070; RCP 6.0 scenario) climatic condition for *Tityus* species in Argentina. Values close to zero and five represent areas with low and high richness of highly dangerous species, respectively.

habits allow the species to thrive even if the external climatic conditions are not favorable if it finds suitable microclimates within urban structures (de Roodt et al., 2014). This may produce cases of omission that is, locals that are not projected by the SDMs but in which the species can nevertheless occur (Guisan and Zimmermann, 2000). Then, our models are conservative because they could underestimate the distribution area of species highly adapted to urban settings.

Recent studies of niche model have shown that *T. serrullatus*, the most dangerous scorpion of South America (Bucaretchi and Baracat, 1995), presents a high climatic suitability in highly populated regions of Brazil as the state of Sao Paulo (Brites-Neto and Duarte, 2015). However, we observed that *T. serrulatus*, did not show environmental continuity between Brazilian and Argentine populations (Fig. S1). Camargo and Richiardi (2000) recorded the occurrence of this species in Corrientes province; however our SDM supports the hypothesis that the presence of the species is the result of accidental transport and not a natural range expansion.

From our SDMs we were able to construct an accident risk map for *Tityus* species (Fig. 2). Our risk map for current climatic conditions shows high concordance with published statistics of accidents as reported by the Ministerio de Salud (Ministry of Health) of Argentina (2011). The Argentine provinces of Santa Fe, Córdoba, Corrientes, Chaco, Santiago del Estero, Tucumán and Jujuy are among those with the higher risks of scorpion stings and envenomation (Fig. 2(a)). The Ministerio de Salud (2011) also emphasizes the provinces of Catamarca and La Rioja as showing a high number of accidents. Our own risk estimation for both provinces showed an intermediate risk level (Fig. 2(a)). In our SDMs *T. confluens* showed high suitability in Catamarca and La Rioja (Fig. 1). We must stress that our risk index does not consider the number of accidents but the toxicity of the venoms and the species richness of the locality. Thus, this small discrepancy may be associated with the species richness estimated by the SDMs for this region. The future potential risk map shows that in the provinces of Entre Ríos and San Luis, the risk of accidents may increase dramatically. Also, the risk maps are generally displaced towards southern Argentina increasing the probability of accidents in central and southern Buenos Aires and La Pampa, while in the provinces of Chaco and Formosa and eastern Salta the probability of accidents will diminish with climate change (Fig. 2(b)).

5. Conclusion

Climate changes have strong consequences for the geographic distribution of species. For this reason, the consideration of the future derivations of global warming is of central importance in the studies of public health problems involving risky animal species. With this perspective, SDMs have become a fundamental tool for predicting potential impacts of climate change on the distributional patterns of wild species such as vectors of disease and venomous species. Our study using SDMs permitted the identification of areas with climatic conditions favorable for the occurrence of dangerous scorpion species and allowed the prediction of future potentially risky areas.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sste.2018.03.002.

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